Fusion Energy: Bringing a Star to Earth

Summary

Fusion energy is arguably one of the most important and rewarding research challenges of the 21st Century. Fusion power produces no troublesome emissions, is safe, and has few, if any, proliferation concerns. It creates no long-lived waste and runs on fuel readily available to all nations. The recent Presidential decision to join the negotiations to participate in the construction of the International Thermonuclear Experimental Reactor (ITER) is a critical step to a demonstration-scale fusion power plant.

Fusion energy is already widely available. Fusion powers every star in the universe. The huge gravitational forces within stars allow them to confine the reacting fuel elements in a plasma in which the lighter elements fuse together to make heavier elements and energy. The challenge of bringing this power down to earth is considerable but scientists have already made enormous progress in this endeavor.

The two principal approaches for confining the fusion fuel[1] on earth are magnetic and inertial. Magnetic fusion relies on magnetic forces to confine the charged particles of the hot plasma fuel while inertial fusion relies on intense lasers or particle beams to compress a pellet of fuel rapidly to the point where fusion occurs, yielding a burst of energy that would be repeated to produce sustained energy.

Determining the dynamics of confined hot plasmas, which contain a turbulent mix of charged particles—subject to magnetic and electric fields, which they must generate internally as well--has stimulated the rapid development of plasma physics. Understanding the behavior of these plasmas requires an understanding of fluid mechanics, magnetohydrodynamics, kinetic theory, nonlinear dynamics and the use of leading-edge computer simulation. Developments in fusion and plasma science have directly contributed to astrophysics, atomic physics, and communication sciences. There have also been many spin-offs in areas such as plasma processing, waste disposal, lighting, and space propulsion.

Over the last decade, there has been extraordinary progress in the ability to model complex plasmas using state-of-the-art computer systems and the ability to measure the internal characteristics of plasmas at near reactor conditions (i.e., temperatures 10 times the surface of the sun). With these advances in simulation and instrumentation our ability to design and build the machines of the future has vastly improved

Several inventive configurations of magnetic fields have been proposed to confine the plasma as it is heated to the conditions necessary for fusion. The most successful have been toroidal systems, especially the Russian-originated tokamak, which is the primary focus of world research today. The fusion power produced in these machines has improved by six orders of magnitude (from a few watts to megawatts) over the past two decades.

In the past two decades, two programs have advanced our knowledge of magnetically confined plasmas. First, at the Tokamak Fusion Test Reactor at the Department of Energy's (DOE's) Princeton Plasma Physics Laboratory, experiments produced 10 Megawatts of power (lasting about a second), and then at the larger Joint European Tokamak near Oxford in the U.K. they achieved longer pulses at higher power. In each case scientists analyzed the results, refining our understanding to the point where we can confidently proceed to the larger-scale ITER burning plasma experiment.

World fusion scientists have designed several burning plasma experiments, in which the actual fusion energy process dominates the power input into the plasma. ITER is the result of many years of collaborative effort (including the U.S. through 1998) and incorporates the world's collective

[1] Deuterium and tritium, two isotopes of hydrogen are the easiest elements to fuse together. The net product of this fusion is helium (an inert gas) and a neutron that carries most of the energy — the deuterium in a gallon of seawater is equivalent to 300 gallons of gasoline.

understanding of how best to construct such an experiment. Canada, Europe, and Japan have offered sites for ITER and negotiations are well under way. The cost of the ITER facility has been reduced almost in half (following earlier U.S. recommendations) and recent developments have also increased confidence that the project will meet its goals.

The Fusion Energy Sciences Advisory Committee (FESAC) has concluded we are technically and scientifically ready to proceed with a burning plasma experiment and has recommended joining the ongoing negotiations to construct ITER. The National Research Council of the National Academy of Sciences has endorsed this strategy. Based on these recommendations and an assessment by DOE's Office of Science of the cost estimate for the construction of ITER, the President has decided that the U.S. should join the ITER negotiations. ITER is expected to be the last major step between today's experiments and a demonstration plant, although much fusion research and development work needs to be done on materials and alternative fusion power system configurations.

In addition to joining ITER, it will be imperative to continue and strengthen the basic elements that have provided the insights leading to the improved ITER design in the first place. The core U.S. strengths in theory and modeling, diagnostics, advanced and innovative concepts, and plasma and fusion technologies will be needed to ensure the success of ITER and the pathway to fusion energy.

Just as the magnetic fusion energy program can gain leverage form international fusion research, U.S. fusion energy efforts may also benefit from the large U.S. defense program investments in inertial fusion. The National Ignition Facility (NIF) is many times larger than any previous inertial confinement device. It presents a unique opportunity to produce information on target compression that could be used in energy-oriented studies using ion beams or newer kinds of lasers to compress the targets for energy purposes.

Fusion energy research offers an opportunity for this generation to provide for the future rather than borrowing from our children by depleting non-renewable natural resources. Our scientists have provided the opportunity. These investments are needed now.

"By the time our young children reach middle age, fusion may begin to deliver energy independence … and energy abundance … to all nations rich and poor. Fusion is a promise for the future we must not ignore." (Secretary of Energy Spencer Abraham, January 30, 2003)

For more information, please contact:

Dr. Anne Davies, Associate Director
Fusion Energy Sciences
Office of Science, U.S. Department of Energy
SC-50, Germantown Building
1000 Independence Avenue, SW
Washington, DC 2085-1290
301-903-4941
anne.davies@science.doe.gov
www.ofes.fusion.doe.gov